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Exposure to natural space, sense of community belonging, and adverse mental health outcomes across an urban region

Emily J. Rugel[a,*], Richard M. Carpiano[b,c,d], Sarah B. Henderson[a,e], Michael Brauer[a]

[a] School of Population & Public Health, 2206 E Mall, Vancouver, BC V6T 1Z9, Canada
[b] School of Public Policy, University of California, Riverside, 900 University Ave., Riverside, CA 92521, USA
[c] Department of Sociology, University of California, Riverside, 900 University Ave., Riverside, CA 92521, USA
[d] Center for Healthy Communities, University of California, Riverside, 900 University Ave., Riverside, CA 92521, USA
[e] British Columbia Centre for Disease Control, 655 W 12th Avenue, Vancouver, BC V5Z 4R4, Canada

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ABSTRACT

In a rapidly urbanizing world, identifying evidence-based strategies to support healthy design is essential. Although urban living offers increased access to critical resources and can help to mitigate climate change, densely populated neighborhood environments are often higher in many of the physical and psychological stressors that are detrimental to health, and lower in the social capital that is beneficial to health. One component of urban form that can reduce these stressors and improve social capital is nature: greenspace, such as parks and street trees, and bluespace, such as rivers and oceans. In this project, we applied measures from a Natural Space Index previously developed for the Vancouver, Canada census metropolitan area to explore the relationship between distinct measures of natural space and prevalence of (1) major depressive disorder, (2) negative mental health, and (3) psychological distress. In addition, we examined direct associations between natural space exposure and neighborhood social capital, as measured via self-reported sense of community belonging (SoC), as well as the potential mental health benefits of natural space mediated via SoC. Using data from the population-based, cross-sectional 2012 Canadian Community Health Survey-Mental Health (weighted n = 1,930,048), we found no direct associations between any measure of natural space and mental health in models adjusted for 11 demographic, socioeconomic, household arrangement, health, and urban design variables. However, publicly accessible neighborhood nature was associated with increased odds of higher SoC. A 1% increase in the percentage of natural space (combined greenspace and bluespace) within 500 m had an odds ratio [95% confidence interval] of 1.05 [1.00, 1.10] for very strong vs. very weak SoC and 1.04 [1.01, 1.08] for somewhat strong vs. very weak SoC. In addition, higher levels of SoC were associated with improvements in all three mental health outcomes. Mediation tests indicated significant indirect effects of both publicly accessible neighborhood nature variables on reductions in psychological distress and reduced odds of negative mental health via increased sense of SoC. This suggests that natural space has the potential to address the pressing issue of social isolation and, in turn, poor mental health faced by residents of dense urban environments.

1. Introduction

In an increasingly urban world (World Health Organization, 2016), identifying evidence-based strategies to guide the design and maintenance of healthy cities is an essential function of public health (Tam, 2017). Urban living has been linked to certain health advantages, including better self-reported health, reduced mortality rates, and a narrowing of health inequities (Vlahov et al., 2005). By reducing the energy requirements for transportation and residential heating and cooling, a shift to denser urban environments may also lower greenhouse gas emissions and facilitate climate change mitigation (Dodman, 2009). Conversely, dense urban living has also been tied to a number of environmental stressors, such as increased noise, crime, air pollution, and overcrowding (Lambert et al., 2015; Parra et al., 2010; Zijlema et al., 2017). These stressors are, in turn, linked to increased odds of depression and anxiety (Gong et al., 2016). Furthermore, architectural designs that support density, such as high-rise towers, have been associated with higher levels of psychological distress and lower levels of social connection (Evans, 2003).

Mental disorders such as anxiety and depression are among the most

* Correspondence to: School of Population & Public Health, 327 – 2206 E Mall, Vancouver, BC V6T 1Z9, Canada.
E-mail address: emilyrugel@gmail.com (E.J. Rugel).

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common non-communicable diseases, and their prevalence is growing steadily, particularly in lower-income nations and among aging populations (World Health Organization, 2017). Although standard approaches to estimating the burden of these disorders rank them among the top ten causes of years lived with disability (YLDs) worldwide (Vos et al., 2017), Vigo et al. (2016) assert that properly accounting for all associated morbidity, including non-lethal self-harm and chronic disease exacerbation, would increase this burden substantially, from 21% to 32% of global YLDs in 2013 (Vigo et al., 2016).

Social isolation is another pressing concern, particularly in countries such as Canada that have large and growing numbers of older and elderly adults (Statistics Canada, 2017a). A meta-analysis of 70 studies linked social isolation to a 29% increase in the likelihood of premature mortality (Holt-Lunstad et al., 2015). A separate review identified cardiovascular disease as a pathway to such premature mortality, linking loneliness and social isolation to a 29% increase in the risk of developing coronary heart disease and a 32% increase in stroke incidence (Valtorta et al., 2016). These studies show the potential harms of the absence of social ties. Conversely, the presence of social ties has a critically important role in human well-being, particularly among individuals under stress (Kawachi and Berkman, 2001). Social connections are especially important with respect to mental health because they offer expressive (e.g., sense of purpose), informational, and instrumental forms of support that can help to reduce anxiety, increase self-esteem, and provide positive influences regarding health-promoting behaviors, which may be more difficult to maintain during periods of psychological distress (Thoits, 2011). Because social connections affect such a multitude of health outcomes and their impact may be cumulative across the lifespan, there have been calls to identify and enact population-level interventions and policies that work to strengthen these connections, particularly among groups with increased vulnerability to isolation and illness (Umberson and Karas Montez, 2010).

Natural space is increasingly recognized as one component of the urban fabric that can reduce the harms of exposure to stressors while facilitating social connections. In urban environments, natural space exists in a range of forms, generally classified as greenspace (e.g., street trees, parks, and overall vegetation) or bluespace (e.g., coastlines, rivers, and lakes). Numerous studies have linked various forms of nature to mental health benefits across urban populations, including: reductions in chronic stress (Ward Thompson et al., 2012) and psychological distress (Pope et al., 2015); improvements in self-reported mental health (Gascon et al., 2015; van den Berg et al., 2016); lower prevalence of depressive symptoms (Cox et al., 2017) and clinician-diagnosed anxiety and depressive disorders (Maas et al., 2009a); and fewer antidepressant prescriptions (Taylor et al., 2015). Not all studies have found such benefits, however: greenspace prevalence had no association with positive mental well-being among a nationally representative sample in England (Houlden et al., 2017); access to bluespace had no association with multiple mental health outcomes in Barcelona, Spain (Gascon et al., 2018); and greater park attractiveness was linked to increased psychological distress among residents of Perth, Australia (Sugiyama et al., 2016).

One potential explanation for these inconsistent findings is the use of relatively broad measures of natural space exposure, which encompass multiple possible mechanistic pathways. Facilitated social contact is one of four pathways that are widely described as producing the beneficial effects of exposure to natural space (de Vries et al., 2013; Maas et al., 2009b). This pathway includes social connectedness, social capital (i.e., the potentially health-enhancing resources linked to community social networks), and social support (Carpiano and Hystad, 2011). The other pathways are: (1) direct psychophysiological benefits, such as improved moods, increases in directed attention, and lowered levels of stress; (2) increased rates and benefits of physical activity; and (3) buffering ecosystem services, including reductions in risks from air pollution, high heat, and excessive noise (James et al., 2015; Lee and Maheswaran, 2010; Rugel, 2015; Tzoulas et al., 2007).

Much like the evidence directly linking natural space to mental health improvements, the evidence regarding indirect influences via social connections is mixed. A recent study in the Catalonia region of Spain found no association between natural spaces and higher levels of social support, precluding potential mediation via this pathway (Triguero-Mas et al., 2015). Yet, Fan et al. (2011) found divergent effects in Chicago, Illinois depending on the type of nature. Decreasing park proximity was positively associated with social support, but the association with higher surrounding greenness was negative, reducing the overall positive effect of nature on stress reduction, a component of psychological well-being (Fan et al., 2011). A Dutch study gives further indication that the definition of natural space matters with respect to mediation via social connections. It found that both the quality and quantity of streetscape greenery were independently associated with increased social cohesion and improved mental health status, but quantity had a larger indirect effect than quality (de Vries et al., 2013). Together, these reports highlight how important the form of natural space may be when examining specific pathways. Higher levels of overall greenness may provide direct psychophysiological benefits, but may also reflect neighborhood designs that impede social connections; the accessibility of natural space may be crucial for enhancing social ties.

This analysis explores the relationship between exposure to multiple measures of natural space and three distinct mental health outcomes across the Vancouver, Canada census metropolitan area (CMA) via the application of components of a previously described Natural Space Index (NSI) (Rugel et al., 2017). Our first objective was to assess whether there was an association between natural space and three mental health outcomes: (1) major depressive disorder, (2) negative mental health, and (3) psychological distress, as measured by a nationally representative survey. Our second objective was to assess whether any associations were mediated by reported sense of community belonging, which has been previously evaluated as an indicator of neighborhood-based social capital (Carpiano and Hystad, 2011; Schellenberg et al., 2017).

2. Materials and methods

2.1. Mental health data

The study was conducted using data from the 2012 Canadian Community Health Survey-Mental Health (CCHS-MH), a population-based, cross-sectional survey periodically undertaken as a complement to the annual Canadian Community Health Survey. Detailed information about the purpose and methods for the survey is available through Statistics Canada (Statistics Canada, 2013), but a brief summary is provided here. The CCHS-MH was designed specifically to collect data on both positive and negative mental health outcomes among Canadians. To ensure that estimates were reliable by province, sex, and four large age categories, the 2012 CCHS-MH used a multi-stage sampling strategy and aimed to enroll 27,500 participants across the nation. The target population comprised all Canadian residents over the age of 14, with the exception of individuals residing on First Nations reserves and other Aboriginal lands, full-time members of the Canadian Forces, and those institutionalized at the time of the survey. Together, these excluded groups comprised approximately 3% of the population (Statistics Canada, 2013). Data collection took place between January and December of 2012 using computer-assisted personal interviews conducted by field interviewers who were trained to question participants either in-person or over the phone (Statistics Canada, 2013). Almost all interviews (87%) were carried out in-person, with the remainder taking place by phone. No proxy interviews were permitted (Statistics Canada, 2013).

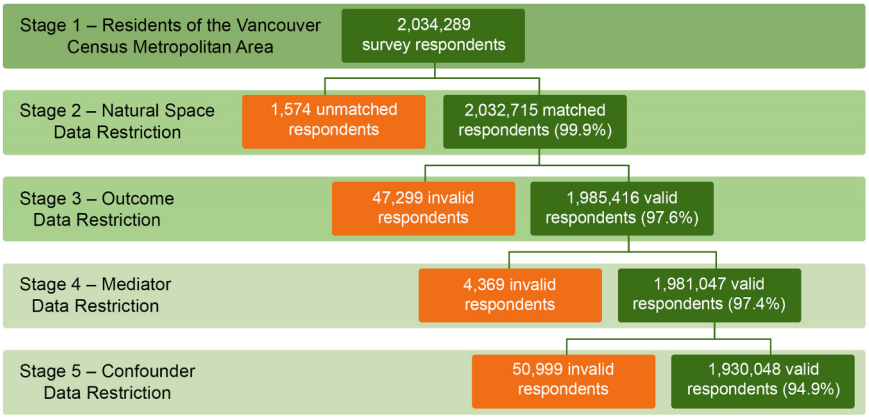
Stage 1 – Residents of the Vancouver Census Metropolitan Area
2,034,289 survey respondents
Stage 2 – Natural Space Data Restriction
1,574 unmatched respondents
2,032,715 matched respondents (99.9%)
Stage 3 – Outcome Data Restriction
47,299 invalid respondents
1,985,416 valid respondents (97.6%)
Stage 4 – Mediator Data Restriction
4,369 invalid respondents
1,981,047 valid respondents (97.4%)
Stage 5 – Confounder Data Restriction
50,999 invalid respondents
1,930,048 valid respondents (94.9%)

Fig. 1. Weighted sample estimates at each stage of analytic sample development. This figure illustrates the criteria used at each stage of restricting the study sample, as well as the loss of respondents associated with each decision. Per Statistics Canada requirements, all figures are weighted.

2.2. Study sample

There were 25,113 interviews completed during the study collection period, for a combined household and individual response rate of 69% (Statistics Canada, 2013). Our natural space variables were only available for the 60,242 six-digit postal codes that were: (1) within the Vancouver CMA – which was home to 2,313,328 residents representing 6.91% of Canada's total population in 2011 (Statistics Canada, 2016) – and (2) included in the Statistics Canada, 2013 postal code conversion file (Peters and Wilkins, 2013). As a result, the study sample was limited to respondents residing within the Vancouver CMA whose postal codes were represented (stage 2 in Fig. 1). As an estimate, based on the total number of completed interviews and the proportion of Canada's residents living within the Vancouver CMA in 2011, approximately 1700 survey respondents would have been expected to reside in the study area. Subsequent exclusions were made due to missing outcome (stage 3 in Fig. 1) and mediator data (stage 4 in Fig. 1). Finally, participants with missing data or unknown responses for any of the study variables were excluded (5%) from the study sample, resulting in a final weighted sample size of 1,930,048 (stage 5 in Fig. 1). In order to comply with privacy regulations, all analyses were conducted within the Statistics Canada Research Data Centre and only weighted values were permitted for reporting.

2.3. Measures

2.3.1. Natural space exposure

Vancouver is the third largest metropolitan area in Canada behind Toronto and Montreal, and it is also one of the most racially and ethnically diverse, with 41% of the population made up of immigrants according to the 2016 Census (Statistics Canada, 2017b). The area's geography is also diverse, ranging from large mountains on the region's North Shore to wetlands and large-scale agricultural areas in the south. The city of Vancouver is separated from the North Shore by the Burrard Inlet, bounded by the Fraser River to the south, and along the Strait of Georgia to the west (City of Vancouver, 2018); these bodies of water also serve as shipping routes served by the Port of Vancouver, Canada's largest port (Port of Vancouver, 2018). Widely known for its urban nature, particularly Stanley Park, Vancouver's tree canopy cover has been steadily declining over the past few decades, falling from 22.5% in 1995 to 20% in 2006 and 18% today (City of Vancouver, 2014), but there are municipal (City of Vancouver, 2012) and regional (Greater Vancouver Regional District Board, 2015) efforts underway to preserve and expand access to natural space for all of the region's 2.46 million residents (Statistics Canada, 2017c).

The Natural Space Index (NSI), which was developed specifically to assess the relationship between natural space and mental health across the Vancouver CMA, is described in detail elsewhere (Rugel et al., 2017). Here, we briefly describe the components of the NSI we used to assess individual measures of natural space, reflecting the presence and accessibility of greenspace and bluespace. The presence of greenspace was based on satellite measurements of the Enhanced Vegetation Index (EVI) from the MODIS instrument that were collected biweekly in 2012 at a 250 m resolution (US NASA, 2016, 2015). The presence of bluespace was based on polygon data indicating the locations and sizes of permanent water features such as oceans, lakes, and rivers, as well as intermittent sources such as sloughs and bogs (DMTI Spatial Inc, 2014a). Such intermittent sources comprise a much smaller percentage of total bluespace than large bodies of water such as the Fraser River, but often play vital roles in local First Nations' history and present-day ecology, with the Camosun Bog (Musqueam Indian Band, 2018) and Finn Slough (City of Richmond, 2018) serving as two prime examples. Specific forms of greenspace included largely green parcels such as golf courses; nature preserves; and local, regional, and provincial parks. Information about parks was drawn from both private databases (DMTI Spatial Inc, 2014b; ESRI, 2014) and publicly accessible online inventories (City of Surrey, 2014; City of Vancouver, 2015; City of White Rock, 2014; District of North Vancouver, 2006; Township of Langley BC, 2014). These inventories were also used along with online searches to classify green parcels as either publicly accessible or restricted, with factors such as entrance fees, permitting requirements, or a need to secure entry in advance leading to assignment to the latter group. No minimum sizes were placed on either green or blue parcels for inclusion in the index, and in the absence of readily available data that might indicate access restrictions for bluespace, all bluespace was considered to be publicly accessible.

All of these data were combined using ArcGIS software, and values were calculated for each layer based on the 100-m centroid of the 60,242 six-digit postal codes in the region. In urban areas within Canada, six-digit postal codes offer robust geographic precision, usually reflecting locations ranging from an individual building to a single block-face (Fuller and Shareck, 2014).

Because the original NSI dataset contained 53 distinct measures at buffers ranging from 100 m to 1600 m, hypotheses regarding the relevance of each individual measure and its most-appropriate buffer size were explored in advance of data analysis. Due to the selection of postal code centroids as the primary unit of exposure assignment, these buffers represent radial distances from the postal code centroid. Based on initial exploration, the following seven measures were selected for inclusion in four categories:

(1) **Surrounding residential greenness:** The *Residential Greenness 250 m* variable was defined as mean EVI in a 250-meter buffer, with bluespace polygons clipped before averaging to properly account

for the negative EVI values created by water sources;

(2) **Visible nature:** *Visible Greenspace 100 m* was defined as greenspace percentage in a 100-meter buffer, and *Visible Natural Space 100 m* was defined as greenspace and bluespace percentage within a 100-meter buffer;

(3) **Accessible neighborhood nature:** *Accessible Greenspace 500 m* was defined as publicly accessible greenspace percentage within a 500-meter buffer, and *Accessible Natural Space 500 m* was defined as public greenspace and bluespace percentage within a 500-meter buffer;

(4) **Binary access to nature:** The *Binary Bluespace 1000 m* variable was based on the presence of bluespace within a 1000-meter buffer, based on prior work showing health benefits of access to bluespace within this proximity (de Vries et al., 2003; Wheeler et al., 2012). The *Binary Greenspace 400 m* variable was defined as an indicator of publicly accessible greenspace within a 400-meter buffer, based on the definition included in the City of Vancouver's Greenest City 2020 Action Plan (City of Vancouver, 2012).

2.3.2. Mental health outcomes

Three primary outcome variables were examined: major depressive disorder, negative mental health, and psychological distress. The variable *Major Depressive Disorder* was based on the CCHS-MH version of the World Health Organization's Composite International Diagnostic Interview (WHO-CIDI), a standardized tool designed to be given by trained lay interviewers to assess mental disorders as part of epidemiologic studies (Harvard Medical School Department of Health Care Policy, 2018). The WHO-CIDI instrument aligns with the criteria and definitions of both the International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10), which is used in medical coding and billing, and the Diagnostic and Statistical Manual of Mental Disorders, 4th Edition (DSM-IV), used by clinicians and other mental health service providers (Statistics Canada, 2013). In addition, the WHO-CIDI tool has shown high concordance with structured clinical interviews used for diagnosis in treatment settings (Kessler et al., 2003a, 2003b). For the purposes of this study, we examined the derived variable for experiencing a major depressive episode in the 12 months prior to the interview (Statistics Canada, 2013).

The variable *Negative Mental Health* was derived from responses to the Mental Health Continuum Short Form (MHC-SF), a scale that comprises 14 items related to emotional well-being and positive functioning (Keyes, 2002). In Keyes' conceptualization, emotional well-being comprises a constellation of measures related to positive feelings about life, including perceived life satisfaction and positive and negative affect. By contrast, positive functioning relates both to aspects of psychological well-being such as self-acceptance and environmental mastery and to social well-being, consisting of dimensions such as social integration and social contribution. Psychometric analysis supports the MHC-SF's reliability and validity within a population-level survey of residents of the Netherlands aged 18–87 (Lamers et al., 2011), and a recent confirmatory factor analysis based on data from the 2012 CCHS-MH found support for the underlying model (Orpana et al., 2017). For this effort, the original three-level classification scheme (Statistics Canada, 2013) was recoded to either negative mental health (based on the categories of "moderate" or "languishing") or positive mental health (based on the category of "flourishing"), to represent the two poles of Keyes' continuum: incomplete versus complete mental health.

Lastly, the variable *Psychological Distress* was derived from the Kessler-10 (K10) Psychological Distress Scale, calculated as a continuous measure ranging from 0 to 40, with higher scores indicating increasing levels of distress. The K10 was originally developed to screen for serious mental illness in large health surveys in lieu of lengthier interviews (Kessler et al., 2003a, 2003b) and multiple validation studies have demonstrated high concordance with clinical appraisals in both general populations and groups with identified mental illness (Kessler et al., 2010).

2.3.3. Mediation

In order to assess potential mediation via social connections, the study integrated the sole relevant item included within the 2012 CCHS-MH: sense of community belonging. The variable *Sense of Community Belonging* (*SoC*) was derived from a single question asking, *"How would you describe your sense of belonging to your local community?"* with response options of "very strong", "somewhat strong", "somewhat weak", "very weak", or "don't know". We excluded participants who did not answer the question or responded "don't know" from the analytic sample. The *SoC* variable is widely used in Canadian health surveys, and prior research has demonstrated that it is most strongly associated with the domain of neighborhood-based social capital (Carpiano and Hystad, 2011). A recent validation study compiled data from three separate Canadian health surveys with a total of more than 60,000 respondents. It corroborated the correlation between *SoC* and network-based social capital, while also noting its relationships to neighborhood satisfaction and place attachment (Schellenberg et al., 2017). We hypothesized that increased values of the *Accessible Greenspace 500 m* and *Accessible Natural Space 500 m* variables would be associated with higher *SoC,* leading to an indirect effect of these natural space exposure measures on mental health improvements, because their accessibility at the neighborhood scale makes them the forms of nature most likely to contribute to neighborhood social cohesion.

2.3.4. Covariates

All potential confounders were selected *a priori* based on relevant literature (Blair et al., 2014; Henderson and Whiteford, 2003; Lambert et al., 2015; Schellenberg et al., 2017; Wood et al., 2010a). If two potentially confounding variables were thought to be collinear, the percent of missing data for each variable was taken into consideration in determining which to include: for example, the World Health Organization's Disability Assessment Schedule was originally assessed as a metric of functional limitations that might both limit use of natural spaces and increase the risk of poor mental health, but pain health status was selected instead due to its higher response rate among eligible participants. The final set of covariates comprised 11 variables: three demographic, two socioeconomic, two household, one physical health, and three urban design (Table 1). Demographic variables were *Sex*, *Age*, and *Race-Ethnicity*. Socioeconomic status was reflected by *Provincial Household Income Level*, which compares the participant with others residing in the same province, and *Highest Household Education Level*. Household type included both *Dwelling Type*, such as single-family home or apartment building, and *Household Living Arrangement*, indicating the presence of and relationship to others in the household. General health was represented by an ordinal *Pain Health Status* variable that reflects both the degree of pain generally felt by participants as well as the extent to which this pain interferes with their daily activities. Finally, urban design was represented by *Urbanicity*, *Population Density*, and *Walkability*. The latter two variables were assigned at the level of census dissemination areas (DAs), containing 400–700 residents (Statistics Canada, 2015), to represent the neighborhood scale. All covariates with the exception of *Population Density* (Statistics Canada, 2012) and *Walkability* (Walk Score Data Services, 2016) were drawn from the CCHS-MH questionnaire.

2.4. Statistical analysis

All analyses were conducted in the Statistics Canada Research Data Centre at the University of British Columbia using SAS, version 9.4. First, descriptive statistics were computed for all variables. Second, conditional logistic regression models were used to explore the relationship between each of the natural space variables and the odds of *Major Depressive Disorder* and *Negative Mental Health*. Generalized logit regression models were then estimated for this same set of explanatory variables and *SoC*, the hypothesized mediator. Third, linear regression models were fitted to the *Psychological Distress* scores, which were

Table 1
Sociodemographic characteristics among Vancouver CMA respondents to the 2012 Canadian Community Health Survey-Mental Health (weighted n = 1,930,048).

	Weighted %
Sex	
Female	52.4
Male	47.6
Age	
15–24 years	17.4
25–34 years	15.3
35–44 years	18.7
45–54 years	19.2
55–64 years	12.8
65 and older	16.5
Ethnicity	
White	49.9
Aboriginal	2.1
East Asian	29.1
South or West Asian	13.9
Black, Latin American, Multiracial/Multiethnic, or Other	5.0
Household income level, relative to other British Columbia respondents	
1st quintile (lowest income)	22.9
2nd quintile	23.5
3rd quintile	20.2
4th quintile	18.2
5th quintile (highest income)	15.1
Highest household education level	
Less than secondary education	13.5
Secondary graduate or some post-secondary education	22.6
Post-secondary graduate	63.9
Dwelling type	
Single, detached	52.4
Apartment building, mobile home, or other	19.3
Duplex, double, row, or terrace	28.3
Household living arrangement	
Unattached, living alone	17.1
Unattached, living with others; or Other	19.4
Couple	20.6
Two-parent family	33.9
Single-parent family	9.0
Pain health status	
No pain	79.0
Doesn't prevent activities	6.7
Prevents a few activities	5.5
Prevents some activities	5.9
Prevents most activities	2.9
Urbanicity	
Urban center core	89.3
Non-urban center core	10.7
	Weighted mean (SE)
Population density (persons per km^2)	7466.26 (317.58)
Neighborhood walkability (Walk Score® summary)	60.18 (0.92)

SE = standard error; all means, percentages, and SEs are rounded.

treated as linear in alignment with previous studies that have examined the relationship between natural space and this measure of mental health (Nutsford et al., 2016). Each model was regressed on a single explanatory variable due to substantial correlations among explanatory variables (Rugel et al., 2017) and in order to support research translation.

All models used sample weights to compute point estimates and 500 baseline replication weights to calculate confidence intervals, per recommendations by Statistics Canada. The *domain* statement was also used within SAS to properly account for the overall stratified sampling design of the survey and the study restriction to individuals residing in the Vancouver CMA. We estimated unadjusted effects and estimates fully adjusted for the 11 covariates.

2.4.1. Assessment of mediation

To test for mediation, we used current best practices to properly account for the complexity of relationships among explanatory, mediator, and outcome variables (Hayes, 2009; MacKinnon et al., 2007). This approach comprises assessing the relationships between: (1) explanatory variables and outcomes, (2) explanatory variables and mediators, and (3) mediators and outcomes. The indirect effect (*ab*) of an explanatory variable associated with a mental health outcome via the *SoC* mediating variable is computed from the relationships (slope coefficients) described in (2) and (3) above. Specifically, *ab* is the product of two slope coefficients, respectively estimating paths *a* and *b*: *path a* is the adjusted slope for the natural space variable of interest when regressed against the mediator (*SoC*), while *path b* is the adjusted slope for *SoC* when the mental health outcome of interest is regressed against the mediator (*SoC*) (as per 3). The statistical significance of *ab* was then determined using the zMediation test, which enables computing standardized indirect effects using estimates obtained from regression models with ordinal, categorical, and linear outcome variables (Iacobucci, 2012).

3. Results

3.1. Sample characteristics

The weighted sample was representative of 1,930,048 individuals, and evenly balanced across sexes and age categories (Table 1). The vast majority of analytic sample members resided in the urban center core (89%) because our sample only included residents of the Vancouver CMA. Slightly more than half lived in single, detached homes (52%) and almost two-thirds had received a certificate, diploma, or degree beyond the high-school level (64%). Half described themselves as White (50%) while almost one-third were East Asian (29%).

3.2. Natural space presence, form, and access

Access to both greenspace and bluespace was fairly high: 44% of sample members had bluespace within a 1000-meter buffer, while 88% met the City of Vancouver's criterion for access to public greenspace within a 400-meter buffer (Table 2). On average, within a 100-meter buffer, 4.3% of the area consisted of greenspace (95% CI = 3.6%, 4.9%), which increased to 4.5% (95% CI = 3.8%, 5.2%) when both greenspace and bluespace were included. Within the 500-meter buffers, these values increased to 9.4% (95% CI = 8.6%, 10.1%) and 11.0% (95% CI = 10.2%, 11.9%), respectively. After clipping bluespace polygons, the mean annual EVI value within a 250-meter buffer was 0.23 (95% CI = 0.23, 0.24).

Table 2
Natural space exposure measures among Vancouver CMA respondents to the 2012 Canadian Community Health Survey-Mental Health (weighted n = 1,930,048).

	Weighted mean (SE)
Residential surrounding greenness	
Residential Greenness 250 m (EVI)	0.23 (0.0)
Visible nature	
Visible Greenspace 100 m (% of area)	4.3 (0.3)
Visible Natural Space 100 m (% of area)	4.5 (0.3)
Accessible neighborhood nature	
Accessible Greenspace 500 m (% of area)	9.4 (0.4)
Accessible Natural Space 500 m (% of area)	11.0 (0.4)
	Weighted % (SE)
Binary access to nature	
Binary Bluespace 1000 m (% yes)	43.9 (2.0)
Binary Greenspace 400 m (% yes)	88.3 (1.2)

SE = standard error; all means, percentages, and SEs are rounded.

Table 3
Adjusted[+] associations between natural space exposure measures and major depressive disorder, negative mental health status, and psychological distress among Vancouver CMA respondents to the 2012 Canadian Community Health Survey-Mental Health (weighted n = 1,930,048).

	Major Depressive Disorder OR (95% CI)	*Negative Mental Health* OR (95% CI)	*Psychological Distress* (Kessler-10 scale) b (95% CI)
Residential surrounding greenness			
Residential Greenness 250 m[a]	0.80 (0.45, 1.42)	1.07 (0.80, 1.44)	0.05 (−0.23, 0.83)
Visible nature			
Visible Greenspace 100 m[b]	1.027 (0.999, 1.055)	1.013 (0.999, 1.026)	0.02 (−0.02, 0.06)
Visible Natural Space 100 m[b]	1.026 (0.998, 1.055)	1.012 (0.999, 1.025)	0.02 (−0.03, 0.06)
Publicly accessible neighborhood nature			
Accessible Greenspace 500 m[b]	0.984 (0.950, 1.020)	1.008 (0.991, 1.025)	− 0.01 (−0.05, 0.02)
Accessible Natural Space 500 m[b]	0.999 (0.968, 1.030)	1.006 (0.991, 1.020)	− 0.02 (−0.05, 0.01)
Binary access to nature			
Binary Bluespace 1000 m[c]	1.72 (0.85, 3.49)	1.20 (0.81, 1.76)	0.68 (−2.05, 3.40)
Binary Greenspace 400 m[c]	1.20 (0.47, 3.07)	1.34 (0.75, 2.42)	0.57 (−1.79, 2.93)

OR = adjusted odds ratio; CI = confidence interval; b = unstandardized slope coefficient.
All odds ratios (OR), 95% confidence intervals (95% CI), and b values are rounded.
[+] Each model includes a single explanatory variable and has been adjusted for sex, age, race-ethnicity, household income level, household education level, dwelling type, living arrangement, pain health status, urbanicity, population density, and Walk Score® walkability.
[a] Models based on a 0.1-unit increase in EVI.
[b] Models based on a 1% increase in area within buffer.
[c] Models based on having access to nature.

3.3. Mental health outcomes and sense of community belonging

The criteria for *Major Depressive Disorder* were met by 4.2% of the sample, and 25.5% were characterized as having *Negative Mental Health*. Rates of both conditions were higher among women (4.9% and 27.0%, respectively) than men (3.5% and 23.9%). Higher-than-average rates of both outcomes were also seen among those living alone (6.3% and 28.1%) and those reporting the most functional interference due to pain (18.4% and 50.8%). The mean *Psychological Distress* scale score was 4.9 (95% CI = 4.5, 5.3), well below the cut-off of 13 for serious mental illness (Kessler et al., 2003a). Most respondents reported very strong (17.3%) or somewhat strong (48.9%) *SoC*, with only 6.8% falling into the lowest category of very weak *SoC*.

3.4. Associations between natural space measures and mental health outcomes

There were no consistent associations between any of the seven natural space measures and the three mental health outcomes in the adjusted models (Table 3). For *Major Depressive Disorder,* the point estimate for the *Binary Bluespace 1000 m* variable was elevated and in the opposite of the hypothesized direction (OR = 1.72; 95% CI = 0.85, 3.49), and the same was true for *Binary Greenspace 400 m* (OR = 1.20; 95% CI = 0.47, 3.07); however, the confidence intervals for both estimates were quite wide and included 1.0. In the anticipated direction, the point estimate for the odds of *Major Depressive Disorder* associated with *Residential Greenness 250 m* (based on each 0.1-point increase in EVI) was 0.80 (95% CI = 0.45, 1.42); however, the confidence interval included 1.0. For *Negative Mental Health*, all of the natural space measures had adjusted odds ratios around 1, with the exception of *Binary Bluespace 1000 m* and *Binary Greenspace 400 m*, which suggested increased odds of having the condition, with ORs of 1.20 (95% CI = 0.81, 1.76) and 1.34 (95% CI = 0.75, 2.42), respectively, although the related confidence intervals also included 1.0. A similar picture emerged for *Psychological Distress*, with coefficients close to zero for all measures except those related to the binary access to nature variables. There were slight increases for both *Binary Bluespace 1000 m* (b = 0.68, 95% CI = -2.04, 3.40) and *Binary Greenspace 400 m* (b = 0.57, 95%CI = -1.79, 2.93), but the confidence intervals spanned zero.

3.5. Associations between natural space measures and sense of community belonging

Consistent with our original hypotheses, we found associations between both measures of accessible neighborhood nature and sense of community belonging as well as a trend in effect sizes, in which higher values of the accessible neighborhood nature variables were associated with increasing odds of reporting higher levels of *SoC*, although many of the confidence intervals for lower levels of *SoC* included 1.0 (Table 4). In adjusted regression models, for each 1% increase in *Accessible Natural Space 500 m* there was a 5% increase in the odds of reporting a “very strong” *SoC* (OR = 1.05; 95% CI = 1.01, 1.10) and a 4% increase in the odds of a “somewhat strong” *SoC* (OR = 1.04; 95% CI = 1.01, 1.08) in comparison with the reference category of “very weak”, with an OR of 1.029 (95% CI = 0.991, 1.067) for “somewhat weak” *SoC*. Similar results were seen for *Accessible Greenspace 500 m*, and effect sizes for both measures were largely the same in unadjusted models (Supplemental Table 1). Based on the point estimates, there was also some evidence of association between higher levels of *SoC* and the *Binary Bluespace 1000 m* and *Binary Greenspace 400 m* variables*:* the adjusted odds ratios were greater than 1 for all three levels in comparison with the reference group of “very weak” but with wide confidence intervals that still included 1.0. Conversely, no associations were evident with the *Residential Greenness 250 m, Visible Greenspace 100 m,* or *Visible Natural Space 100 m* measures, with all confidence intervals spanning 1.0 in both adjusted and unadjusted models.

3.6. Associations between sense of community belonging and mental health outcomes

The *SoC* variable was associated with improvements across all three mental health outcomes in adjusted regression models (Table 5). In fully adjusted models, there was an 86% decrease in the odds of *Major Depressive Disorder* among individuals reporting a “very strong” *SoC* (OR = 0.14; 95% CI = 0.03, 0.66) and a 78% decrease among individuals with a “somewhat strong” *SoC* (OR = 0.22; 95% CI = 0.08, 0.63) in comparison with the reference category of “very weak”; the OR among individuals with a “somewhat weak” *SoC* was 0.41 (95% CI = 0.15, 1.10). For *Negative Mental Health*, the decreases were 91% (OR = 0.09; 95% CI = 0.03, 0.22) and 78% (OR = 0.22; 95% CI = 0.12, 0.39) for

Table 4
Adjusted[+] associations between natural space exposure measures and sense of community belonging level among Vancouver CMA respondents to the 2012 Canadian Community Health Survey-Mental Health (weighted n = 1,930,048).

	Sense of community belonging level *(reference = very weak)*		
	Somewhat weak OR (95% CI)	Somewhat strong OR (95% CI)	Very strong OR (95% CI)
Residential surrounding greenness			
Residential Greenness 250 m[a]	1.13 (0.74, 1.74)	1.03 (0.68, 1.56)	0.86 (0.50, 1.48)
Visible nature			
Visible Greenspace 100 m[b]	0.999 (0.971, 1.028)	1.009 (0.982, 1.036)	1.008 (0.978, 1.038)
Visible Natural Space 100 m[b]	0.999 (0.972, 1.028)	1.010 (0.984, 1.038)	1.009 (0.980, 1.039)
Publicly accessible neighborhood nature			
Accessible Greenspace 500 m[b]	1.033 (0.996, 1.082)	1.038 (0.990, 1.089)	1.051 (1.002, 1.103)
Accessible Natural Space 500 m[b]	1.029 (0.991, 1.067)	1.042 (1.005, 1.081)	1.052 (1.011, 1.095)
Binary access to nature			
Binary Bluespace 1000 m[c]	1.60 (0.84, 3.07)	1.42 (0.76, 2.67)	1.69 (0.83, 3.42)
Binary Greenspace 400 m[c]	1.18 (0.48, 2.91)	1.36 (0.59, 3.13)	1.07 (0.39, 2.96)

OR = adjusted odds ratio; CI = confidence interval.
All odds ratios (OR) and 95% confidence intervals (95% CI) are rounded.
[+] Each model includes a single explanatory variable and has been adjusted for sex, age, race-ethnicity, household income level, household education level, dwelling type, living arrangement, pain health status, urbanicity, population density, and Walk Score® walkability.
[a] Models based on a 0.1-unit increase in EVI.
[b] Models based on a 1% increase in area within buffer.
[c] Models based on having access to nature.

"very strong" and "somewhat strong" SoC, respectively, with an OR of 0.69 (95% CI = 0.37, 1.28) for "somewhat weak". Finally, for *Psychological Distress*, the two highest levels of *SoC* were associated with reductions in K10 scores in comparison with the reference category of "very weak": a 2.8-point reduction [-4.4, -1.2] for those in the "very strong" category and a 2.0-point reduction [-3.5, -0.6] for those in the "somewhat strong" category, with a beta of -1.1-point [-2.5, 0.4] for those in the "somewhat weak" category. These general relationships were also seen in unadjusted models – although many effect sizes were smaller (Supplemental Table 2) – as well as in models that were adjusted for the natural space exposure measures associated with sense of community belonging along with all confounding variables (Supplemental Table 3).

3.7. Testing the indirect effect of sense of community on mental health outcomes

The two criteria for proceeding to a zMediation test of the significance of an indirect effect were met for both the *Accessible Greenspace 500 m* and the *Accessible Natural Space 500 m* variables and at least one higher level of *SoC* in comparison with the "very weak" reference group: (1) each of these explanatory variables was associated with the hypothesized mediator; and (2) the hypothesized mediator was associated with at least one mental health outcome (after controlling for the explanatory variable; reported in Supplemental Table 3). Based on these results (Table 6), at an alpha of 0.05, there was a statistically significant indirect effect of *Accessible Greenspace 500 m* on lowered *Psychological Distress* for individuals reporting a "very strong" *SoC* and those reporting a "somewhat strong" *SoC*; this was also true for *Accessible Natural Space 500 m*. Looking at *Negative Mental Health,* the test was significant for both *Accessible Greenspace 500 m* and *Accessible Natural Space 500 m*, but only among those with a "somewhat weak" *SoC*. There were no significant indirect effects of either natural space exposure measure on the odds of *Major Depressive Disorder*.

4. Discussion

This study explored associations between seven measures of natural space exposure and three mental health outcomes, and then tested potential mediation via social cohesion using population-level health survey data. We found no evidence for a direct association in the expected direction between any of seven measures of natural space with the *Major Depressive Disorder*, *Negative Mental Health*, or *Psychological Distress* outcomes. However, higher percentages of the *Accessible Greenspace 500 m* and *Accessible Natural Space 500 m* variables were linked to higher levels of *SoC*, which were, in turn, associated with improvements across all three mental health measures (Fig. 2). Using the zMediation test, we found indirect effects of *Accessible Greenspace 500 m* and *Accessible Natural Space 500 m* on both reduced *Psychological Distress* and lower odds of *Negative Mental Health* via higher levels of *SoC*. This finding highlights the importance of social ties for mental well-being and supports the results of earlier studies that demonstrated

Table 5
Adjusted[+] associations between sense of community belonging level and major depressive disorder, negative mental health status, and psychological distress among Vancouver CMA respondents to the 2012 Canadian Community Health Survey-Mental Health (weighted n = 1,930,048).

	Major Depressive Disorder OR (95% CI)	*Negative Mental Health* OR (95% CI)	*Psychological Distress* (Kessler-10 scale) b (95% CI)
Sense of community belonging level			
Very weak	Referent	Referent	Referent
Somewhat weak	0.41 (0.15, 1.10)	0.69 (0.37, 1.28)	− 1.06 (−2.54, 0.42)
Somewhat strong	0.22 (0.08, 0.63)	0.22 (0.12, 0.39)	− 2.04 (−3.49, −0.59)
Very strong	0.14 (0.03, 0.66)	0.09 (0.03, 0.22)	− 2.79 (−4.39, −1.19)

OR = adjusted odds ratio; CI = confidence interval; b = unstandardized slope coefficient.
All odds ratios (OR), 95% confidence intervals (95% CI), and b values are rounded.
[+] Each model has been adjusted for sex, age, race-ethnicity, household income level, household education level, dwelling type, living arrangement, pain health status, urbanicity, population density, and Walk Score® walkability.

Table 6
Results of zMediation test[+] of indirect effect of sense of community belonging level on associations between natural space exposure measures and mental health outcomes among Vancouver CMA respondents to the 2012 Canadian Community Health Survey-Mental Health (weighted n = 1,930,048).

	Major Depressive Disorder $Z_{Mediation}$	*Negative Mental Health* $Z_{Mediation}$	*Psychological Distress* (Kessler-10 scale) $Z_{Mediation}$
Accessible Greenspace 500 m[a]			
Sense of community belonging			
Very weak	Referent	Referent	Referent
Somewhat weak	0.82	2.05*	− 1.39
Somewhat strong	0.43	0.67	− 2.75*
Very strong	0.17	0.17	− 3.40*
Accessible Natural Space 500 m[a]			
Sense of community belonging			
Very weak	Referent	Referent	Referent
Somewhat weak	0.79	2.03*	− 1.37
Somewhat strong	0.41	0.65	− 2.70*
Very strong	0.16	0.16	− 3.35*

All test results are rounded.
[+] Tests were carried out using the formula detailed in Iacobucci (2012) and based on the results of the regression models reported in Table 4 and Supplemental Table 3.
[a] Models based on a 1% increase in area within buffer.
* Statistically significant at α = 0.05.

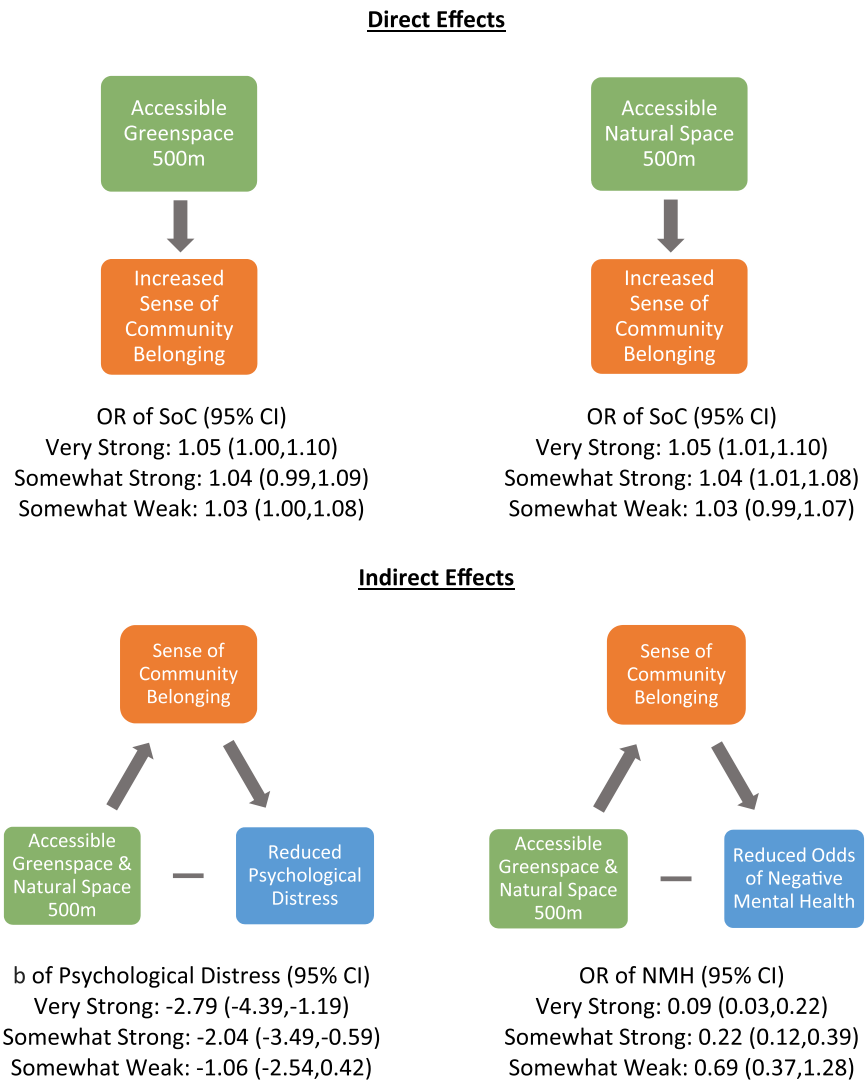
Direct Effects
Accessible Greenspace 500m
Increased Sense of Community Belonging
OR of SoC (95% CI)
Very Strong: 1.05 (1.00,1.10)
Somewhat Strong: 1.04 (0.99,1.09)
Somewhat Weak: 1.03 (1.00,1.08)
Accessible Natural Space 500m
Increased Sense of Community Belonging
OR of SoC (95% CI)
Very Strong: 1.05 (1.01,1.10)
Somewhat Strong: 1.04 (1.01,1.08)
Somewhat Weak: 1.03 (0.99,1.07)
Indirect Effects
Sense of Community Belonging
Accessible Greenspace & Natural Space 500m
Reduced Psychological Distress
b of Psychological Distress (95% CI)
Very Strong: -2.79 (-4.39,-1.19)
Somewhat Strong: -2.04 (-3.49,-0.59)
Somewhat Weak: -1.06 (-2.54,0.42)
Sense of Community Belonging
Accessible Greenspace & Natural Space 500m
Reduced Odds of Negative Mental Health
OR of NMH (95% CI)
Very Strong: 0.09 (0.03,0.22)
Somewhat Strong: 0.22 (0.12,0.39)
Somewhat Weak: 0.69 (0.37,1.28)

Fig. 2. Direct and indirect relationships between publicly accessible neighborhood nature, mental health outcomes, and sense of community belonging. This figure summarizes the direct and indirect associations found among natural space, mental health, and sense of community belonging. Arrows depict statistically significant relationships, while dashes indicate a lack of statistically significant effects. Exposure variables appear in green, mediating variables in orange, and outcome variables in blue.

a role for neighborhood natural space in various measures of social connections (Fan et al., 2011; Holtan et al., 2015; Ulmer et al., 2016), including others that have used 500-meter buffers to define neighborhoods (Dadvand et al., 2016; Dzhambov et al., 2018). In addition, it indicates the potential importance of publicly accessible neighborhood nature in addressing issues of both social isolation and poor mental health in dense urban environments.

The lack of direct associations between urban nature and improved mental health adds to the mixed results arising from population-level studies. The extent to which existing evidence is unclear is well-described in Gascon et al.'s (2015) systematic review. Gascon's work points to the following factors as potential causes of variability in the relationships between urban nature and mental health: lack of consensus regarding how best to define and capture exposure to nature; a lack of clarity with respect to the relationship between pathways and forms; and the failure to explore how other elements of the built environment may influence exposure to natural space (Gascon et al., 2015). Our results highlight some of these potential factors, as well as pointing to the necessity of exploring indirect pathways, such as the social cohesion examined here.

The potential impact of other elements of urban design is supported by our findings that unadjusted models indicated a role for *Residential Greenness 250 m* in reduced odds of *Major Depressive Disorder* (Supplemental Table 4), but that models adjusted for both *Population Density* and *Walkability* showed no such effect (full model results for all covariates will be provided upon request). This may indicate that some of the health benefits previously ascribed to surrounding greenness are actually due to other aspects of the urban form, such as the design of street networks or the presence of large open areas on private property. Although the extent of such unmeasured confounding is challenging to quantify, a recent study of more than one million Canadians linked a one interquartile range increase in NDVI to reductions of 9–10% in the hazard of premature mortality. The same study found that controlling for population density reduced hazard ratios by 4%, as much as controlling for levels of the air pollutant nitrogen dioxide (Crouse et al., 2017). Walkability may be particularly important to consider when social interaction is the pathway of interest. Residents of highly walkable neighborhoods in Galway, Ireland had 80–95% higher odds of high social capital than those in less walkable neighborhoods (Leyden, 2003), and individual components of walkability were linked to a greater sense of community belonging among adult residents of Atlanta, Georgia (Wood et al., 2010b).

Another potential explanation for our results is our use of objective outcomes. One of the few efforts to examine clinical diagnoses of anxiety and depression found a relatively weak association between these conditions and the percentage of large natural spaces within a 1-kilometer buffer, with a 10% increase over the average associated with a 4% reduction in the odds of depression and a 5% reduction in the odds of anxiety (Maas et al., 2009c). In addition, a number of studies that have found positive associations with objective mental health outcomes have relied on much coarser geographic scales than the six-digit postal code. Boroughs were used as the unit of analysis in an ecological assessment of antidepressant prescriptions in London, England (Taylor et al., 2015). Another English study used Lower Layer Super Output Areas (with up to 3000 residents) (United Kingdom Office for National Statistics, 2018) to link increased greenspace to improvements on the General Health Questionnaire, a screening tool for mood disorders (White et al., 2013).

Yet another relevant factor is the heterogeneity of exposure measures used in earlier studies examining natural space. For instance, multiple reports have pointed to greater mental health improvements from bluespace as compared with greenspace (Huynh et al., 2013). These include a qualitative study conducted with older adults from the Vancouver region (Finlay et al., 2015) and a more recent study examining psychological distress in Wellington, New Zealand (Nutsford et al., 2016). Although we also observed differences between bluespace and greenspace, our measure of *Binary Bluespace 1000 m* was linked to increased, rather than decreased, odds of *Major Depressive Disorder* and adding bluespace to the measure of *Accessible Greenspace 500 m* (i.e., the *Accessible Natural Space 500 m* variable) had little impact on its association with *SoC*.

Our results regarding the relationship between publicly accessible neighborhood nature and sense of community belonging also support calls for increased attention to the importance of selecting natural forms in light of relevant pathways (de Vries et al., 2013; Gascon et al., 2015). The differential effects of specific natural forms on measures of social connections may also explain the null findings seen in other studies that have explored this pathway, including one that looked at both surrounding greenness and access to greenspace and bluespace within a 300-meter buffer, but did not account for private versus public access (Triguero-Mas et al., 2015). The importance of accessibility has also been identified with respect to mental health benefits, including a study that found 42% lower odds of psychological distress among individuals who reported that greenspaces were accessible versus inaccessible (Pope et al., 2015).

Our study is not the first to find evidence for an indirect effect of natural space on mental health improvements via social connections in the absence of a direct effect. Using residential tree canopy cover within a 250-meter buffer as its definition of nature, a cross-sectional study based on data from the California Health Interview Survey found no associations with psychological distress. However, it did report an association with the odds of reporting higher levels of perceived neighborhood social cohesion, derived from a three-question index regarding the neighborhood social environment – although a very small one, with an OR of 1.014 (95% CI = 1.004, 1.023) associated with a 10% increase in tree cover. Even at this effect size, however, neighborhood social cohesion mediated 11% of the overall relationship between tree canopy and general health (Ulmer et al., 2016). Another study investigated multiple mediators of the relationship between three distinct measures of natural space exposure and subjective general health. It found evidence for mediation via perceived social support for both surrounding greenness (based on NDVI within 100 m, 250 m, and 500 m buffers) and subjective proximity to greenspace (based on participants' reports of having a park within a ten-minute walk of home) – with increased odds of 15–22% associated with the former and 31% with the latter – as well as indicating that 500-meter buffers were most relevant for social connections (Dadvand et al., 2016). Our study adds specificity to these findings by focusing on objective, clinically relevant mental health outcome measures rather than general health. Although it is somewhat challenging to compare results across studies due to the varying exposure types and measures of social connections, our effect sizes are close to those found by Ulmer et al. (Ulmer et al., 2016), but substantially lower than those reported in Dadvand and colleagues' study (Dadvand et al., 2016), which may reflect the tighter alignment between the constructs of sense of community belonging and neighborhood social cohesion (Schellenberg et al., 2017).

In addition to the use of objective mental health outcomes that align with clinical diagnoses, our study has a number of strengths. Principal among these is the use of data from the CCHS-MH, a health survey that was specifically designed to examine mental health across a representative sample of the population. These data also allowed us to incorporate a large number of potential confounders, adding to the interpretability of adjusted models. The selection of natural space measures and buffer sizes based on distinct pathways is another strength, as is the inclusion of measures that align with local sustainability plans. Finally, our use of best practices for assessing mediation (Hayes, 2009; MacKinnon et al., 2007) via the zMediation test (Iacobucci, 2012) represents an advancement over the many other studies that have examined potential pathways linking nature to mental health using Baron and Kenny's classical four-step approach (Dadvand et al., 2016; Gubbels et al., 2016; Ward Thompson et al., 2016; Zijlema et al., 2017).

4.1. Limitations

There are several limitations to this study. Most importantly for a study examining mediation, we are unable to address causality due to the cross-sectional nature of the CCHS-MH. In addition, even though we controlled for walkability and population density, the potential for unmeasured confounding via built-environment factors remains. This is particularly true because the reliance on six-digit postal codes to assign exposure did not allow us to assess the role of street networks in accessibility to natural spaces. Overall, however, using six-digit postal codes as a proxy for residential location results in little spatial error in urban regions within Canada (Fuller and Shareck, 2014).

Our ability to broadly address potential mediation via social connections is also restricted by the reliance on the sole relevant variable within the CCHS-MH, sense of community belonging, which is based on responses to a single Likert-scale questionnaire item. Although the measure is widely used in Canadian population health studies and has been corroborated using data on more-discrete measures of social capital embedded in other population-based studies (Schellenberg et al., 2017), it is still reflective of just one component of the complex array of social ties that are critical to a range of health domains (Thoits, 2011). Ideally, future efforts will be able to integrate measures reflecting specific aspects of social connectedness, allowing for additional insights into this causal pathway.

In addition, although interviews for the CCHS-MH survey were carried out between January and December of 2012, the natural space measures were based on data collected between 2014 and 2016, leading to a temporal mismatch. This may have resulted in misclassification error for a measure such as *Binary Greenspace 400 m*, which could potentially include public park space unavailable at the time of the survey. However, a measure such as *Binary Bluespace 1000 m* that primarily reflects large bodies of water is unlikely to be impacted, and studies that have examined residential greenness in cohort studies have found that this measure of natural space also remains stable over time (Fuertes et al., 2016).

More greenspace may make neighborhoods more attractive, which may lead to escalating housing costs. This can cause upward shifts in area-level economic status and lead to displacement via gentrification (Wolch et al., 2014), making this another potential source of unmeasured confounding via area-level socioeconomic status. Unfortunately, the 2012 CCHS-MH omits any relevant area-level measures, and data quality from the 2011 Canadian Census long form was compromised (Smith, 2015), which prevented us from assigning such measures from an external source. The CCHS-MH survey does include a robust set of household SES measures, and we adjusted for these in our models. Previous studies have also pointed to potential moderation via urbanicity, but the low proportion of individuals residing outside the urban core precluded full exploration of this issue.

This limitation primarily affects the generalizability of our findings, as does the fact that the Vancouver CMA is a region with relatively high levels of naturalness, as demonstrated by the high average EVI and large percentages of participants with access to both greenspace and bluespace. Our mean value for residential surrounding greenness within a 250-meter buffer was 0.23, for instance, while an effort in Barcelona that also explored associations between this exposure metric and social interaction reported a mean almost 20% lower, at 0.19 (Dadvand et al., 2016). However, our rate of access to public greenspace within 400 m conforms closely with those found in a multi-city effort to develop an urban greenspace indicator for Europe, at 88% in comparison to their range of 86–97% depending on the locale in question (Annerstedt van den Bosch et al., 2016). These relatively high levels of natural space exposure also resulted in low contrast for the binary access measures, which may have led to a lack of power to robustly detect their effects, as demonstrated by the large effect estimates and wide confidence intervals. Because a wide range of sociodemographic factors is known to affect self-reported sense of community belonging – including gender, age, individual and area-level income, and housing design (Schellenberg et al., 2017) – caution is also warranted in applying the mediation results to cities with markedly different demographic profiles. In general, because urban nature is always embedded in complex physical and social environments, we would argue that the body of literature regarding the impacts of urban natural spaces on health is inherently tied to place.

5. Conclusions

Our study did not find evidence for a direct effect of exposure to urban natural space on mental health outcomes in the expected direction. However, it did provide evidence for the role of natural space in facilitating social connections and for providing indirect mental health benefits via increased sense of community belonging. Positive social connections may be particularly vital for urban residents in comparison with their suburban or rural counterparts due to the increased spatial proximity of social networks (Corburn, 2015). Identifying environmental supports for social interaction is crucially important in the Vancouver CMA, where residents consistently rank social isolation as one of their biggest concerns (Vancouver Foundation, 2017). Future research should explore whether these impacts can be ascribed to all members of an urban population equally, in particular the extent to which members of groups with additional vulnerability to isolation may benefit, and further elucidate how best to integrate nature into the urban fabric in order to maximize its positive effects for all urban residents.

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Declaration of interest

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Ethics

This study received initial and ongoing ethics approvals from the University of British Columbia's Behavioural Research Ethics Board under project number H15-01437.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envres.2019.01.034.

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